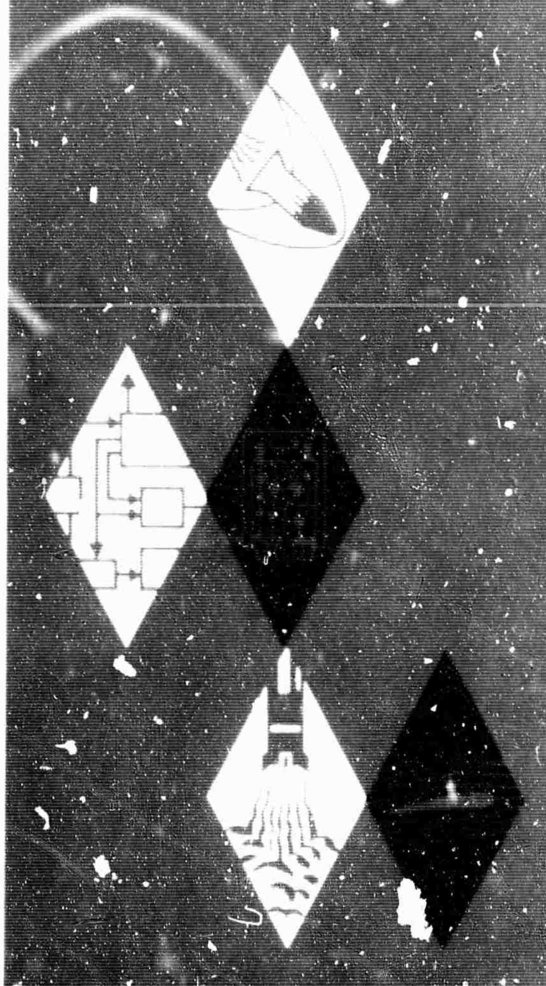
AD 609196

AEROSPACE RESEARCH • AERODYNAMICS • PROPULSION • STRUCTURAL DYNAMICS • ELECTRONIC SYSTEMS AND INSTRUMENTS • COMPUTER MODULES



RESEARCH
ENGINEERING
PRODUCTION

TECHNICAL REPORT NO. 478

FLOW FIELD OF A SPHERICAL PELLET AT BALLISTIC RANGE CONDITIONS IN ARGON

By G. F. Widhopf

December 8, 1964

GENERAL APPLIED SCIENCE LABORATORIES, INC.
MERRICK and STEWART AVENUES, WESTBURY, L.I., N.Y. · (516) ED 3-6960

Project 8010

Total No. of Pages - iii & 23

Copy No. (33) of 105

TECHNICAL REPORT NO. 478

FLOW FIELD OF A SPHERICAL PELLET AT BALLISTIC RANGE CONDITIONS IN ARGON*

By G. F. Widhopf

Prepared for

Advanced Research Projects Agency
Washington 25, D. C.

Under Contract SD-149
ARPA Order No. 396
Project Code 3790

Project Engineer - W. Daskin
Code 516 - ED 3-6960

Prepared by

General Applied Science Laboratories, Inc.
Merrick and Stewart Avenues
Westbury, L. I., New York

Approved by: Walter Daskin for
Antonio Ferri
President

*This research is sponsored by the Advanced Research Projects Agency

December 8, 1964

LIST OF SYMBOLS

P	pressure
P_s	$\rho_\infty u_\infty^2$
ρ	density
R_N	nose radius
S	coordinate along body
T	temperature
U	velocity
X	axial coordinate measured from nose of body
x'	axial coordinate measured from origin of trailing shock
Y	radial coordinate
Y_s	shock coordinate

SUBSCRIPTS

∞	free stream conditions
Δ	edge of viscous region

LIST OF FIGURES

TECHNICAL REPORT NO. 478

FLOW FIELD OF A SPHERICAL PELLET AT BALLISTIC RANGE CONDITIONS IN ARGON

By G. F. Widhopf

This report was prepared in response to a request by personnel of Lincoln Laboratory to have available a detailed description of the flow field of a spherical pellet, at a specified ballistic range condition (V_∞ = 20 kfps; P_∞ = 50 mm Hg), in argon. A similar calculation of flow field details has been performed for an air atmosphere at the aforementioned velocity and pressure; the results are reported in Ref. 1.

In a regime where the Reynolds number is high and the Prandtl* and Schmidt** numbers are on the order of one, transport property effects can be assumed to be localized. Therefore viscous phenomena which occur in the flow about a reentry vehicle are assumed to be restricted to the boundary layer and thus the inviscid and viscous portions of the field may be

---

*Prandtl No. $\equiv P_r \equiv \dfrac{C_p\mu}{k} = \dfrac{\text{viscous}}{\text{thermal}}$ transports.

**Schmidt No. $\equiv S_c \equiv \dfrac{\mu}{\rho D_{12}} = \dfrac{\text{viscous}}{\text{diffusive}}$ transports.

calculated independently. Chemical diffusion effects are also localized; thus a chemically reacting field, as well as one in equilibrium, can be solved locally and independently.

Utilizing these assumptions and the analyses reported in Refs. 2-4 the flow field about a 3/16 inch diameter spherical pellet, at the forenoted ballistic conditions in argon, has been examined. Whereas the previously reported air flow field (Ref. 1) was calculated as being a chemical non-equilibrium continuum, the argon field has been assumed to be in thermo-chemical equilibrium.

Since argon is a monatomic gas it cannot dissociate, thus the extreme shock heating resulting from the strong curved bow shock cannot be absorbed by a dissociation process as in air. The translational temperature for argon is therefore much higher than that for air (e.g. Fig. 4 and Fig. 16, Ref. 1).

An examination of Fig. 1, which compares the physical dimensions of the air and argon flow fields, shows a marked difference between the stand-off distances of the corresponding bow shock $\left(\frac{\text{argon}}{\text{air}} \approx 2.7 \text{ at the stagnation point}\right)$. The angle of the trailing shock and the initial wake dimensions also differ while the viscous wake growth rate is seen

to be lower for argon than air. This difference in growth rates can be accounted for by the higher temperatures existing in the argon wake and the associated larger diffusion time scale.

Similar to Ref. 1 this report includes the pertinent distributions of properties along the body streamline and streamwise variations in the viscous wake. Also included are viscous and inviscid profiles at various axial stations. These properties are shown in Figs. 1-19 where the different regions of the flow field are presented separately, as indicated in the List of Figures.

REFERENCES

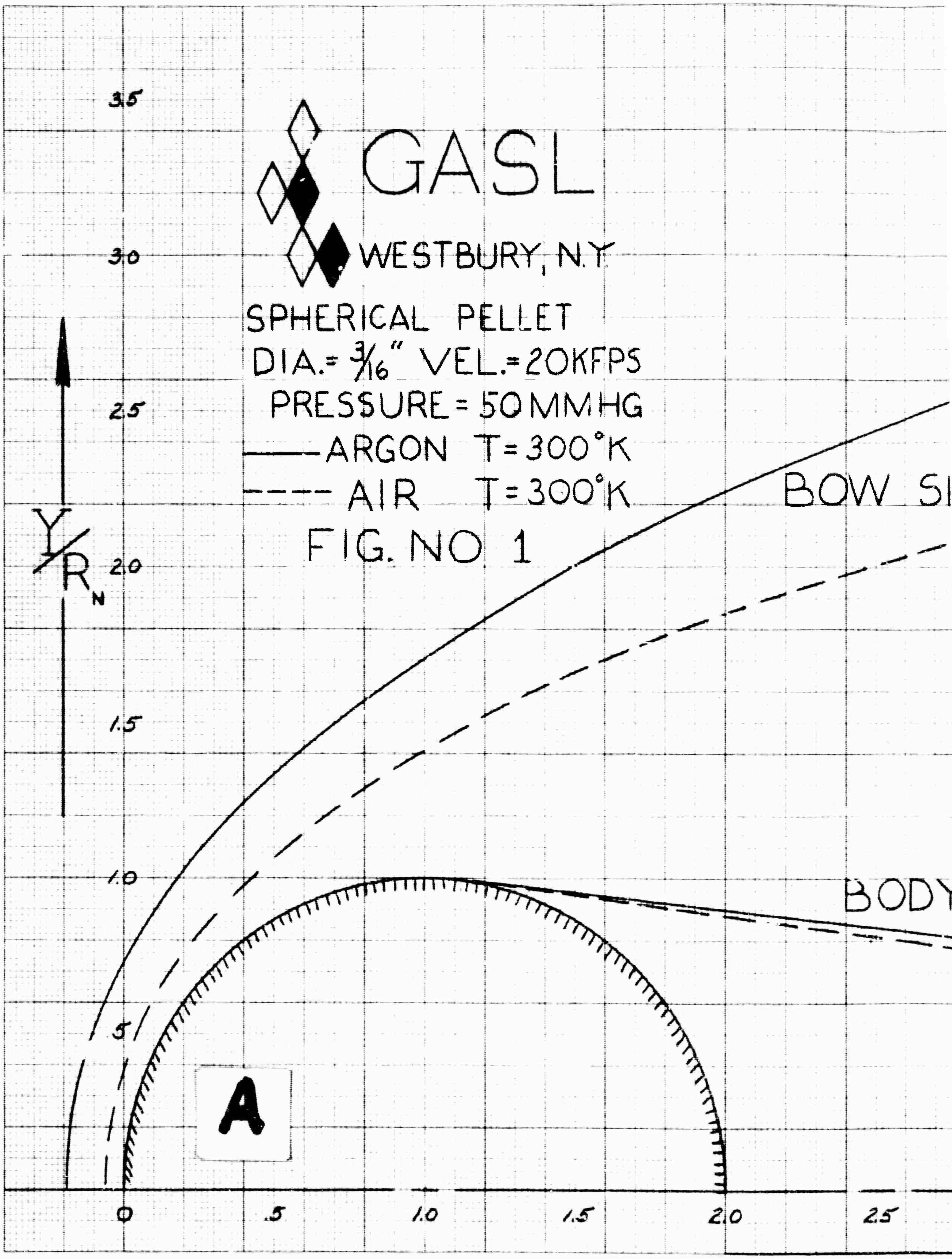
1. Widhopf, G., Zeiberg, S.L., Flow Field of a Spherical Pellet at Ballistic Range Conditions in Air, GASL TR No. 464, Dec. 1964.

2. Lieberman, E., Description of IBM 709/90/94 Computer Programs and Analysis for Flow Fields about Bodies of Revolution in Hypersonic Flight, GASL TR 340, May 1963.

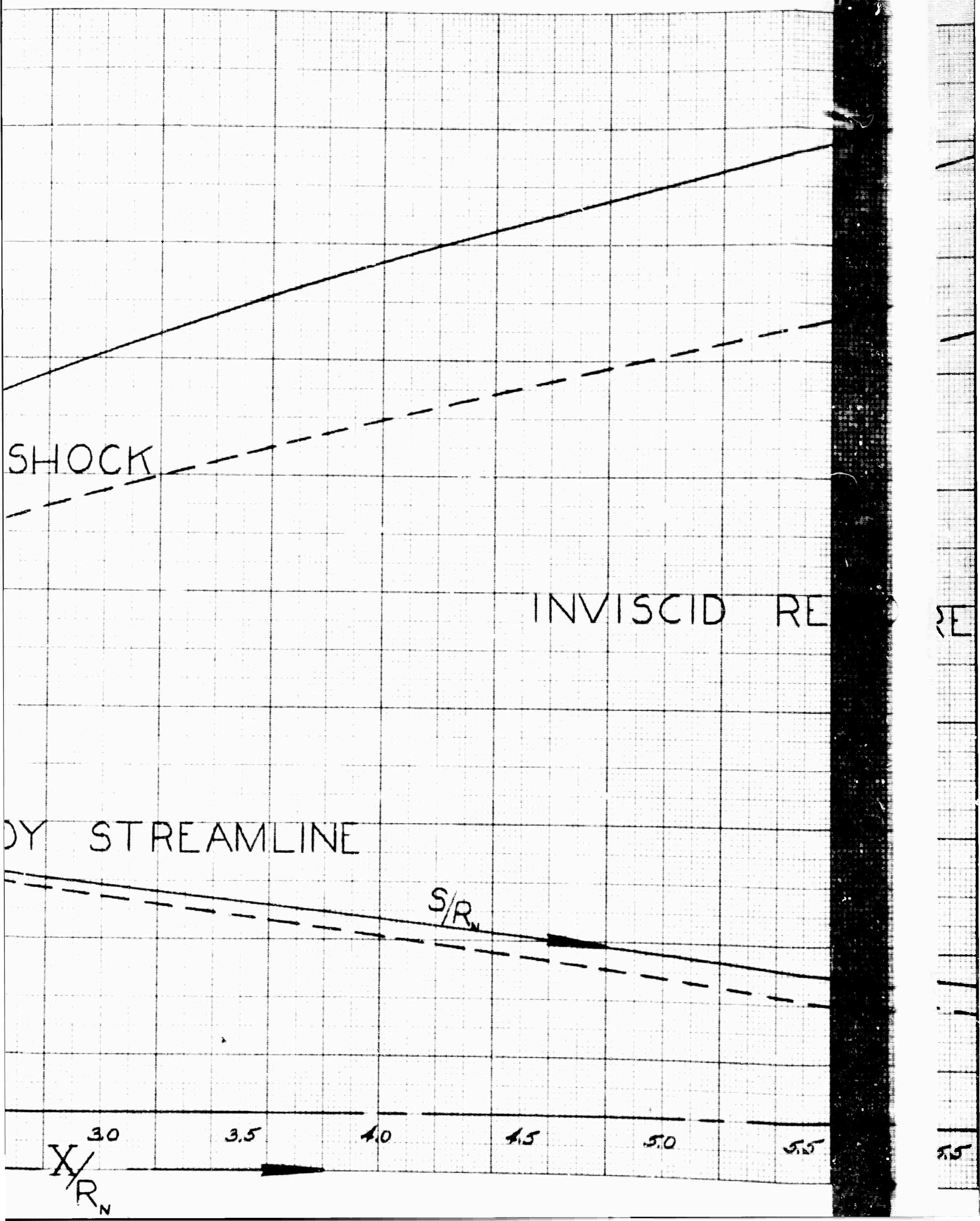
3. Zeiberg, S.L., Bleich, G.D., Finite Difference Calculation of Hypersonic Wakes, AIAA Preprint 63-448, AIAA Journal, August 1964

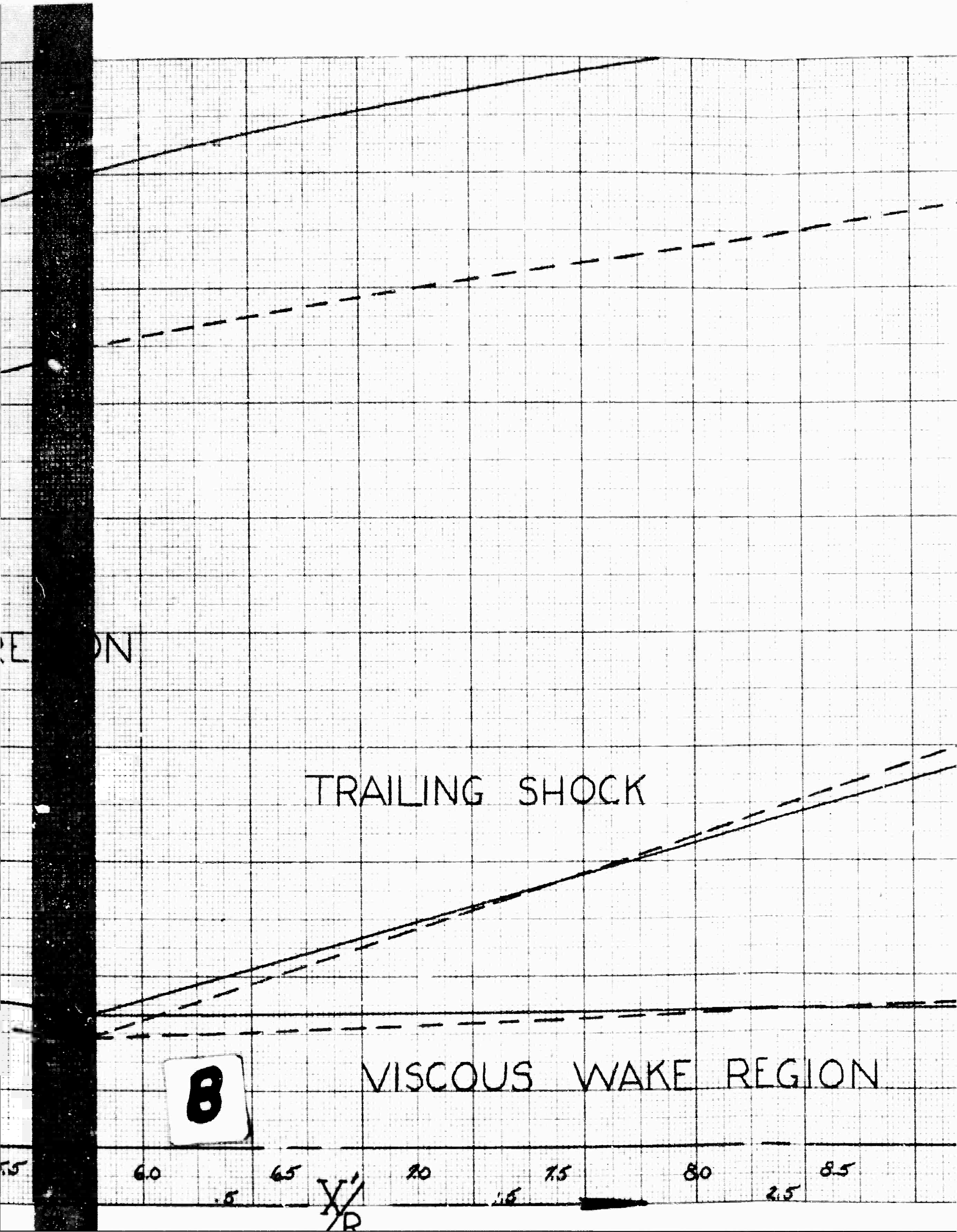
4. Zeiberg, S.L., Bleich, G.D., The Blunt Body Hypersonic Wake, GASL TR No. 451, August 1964.

BLANK PAGE

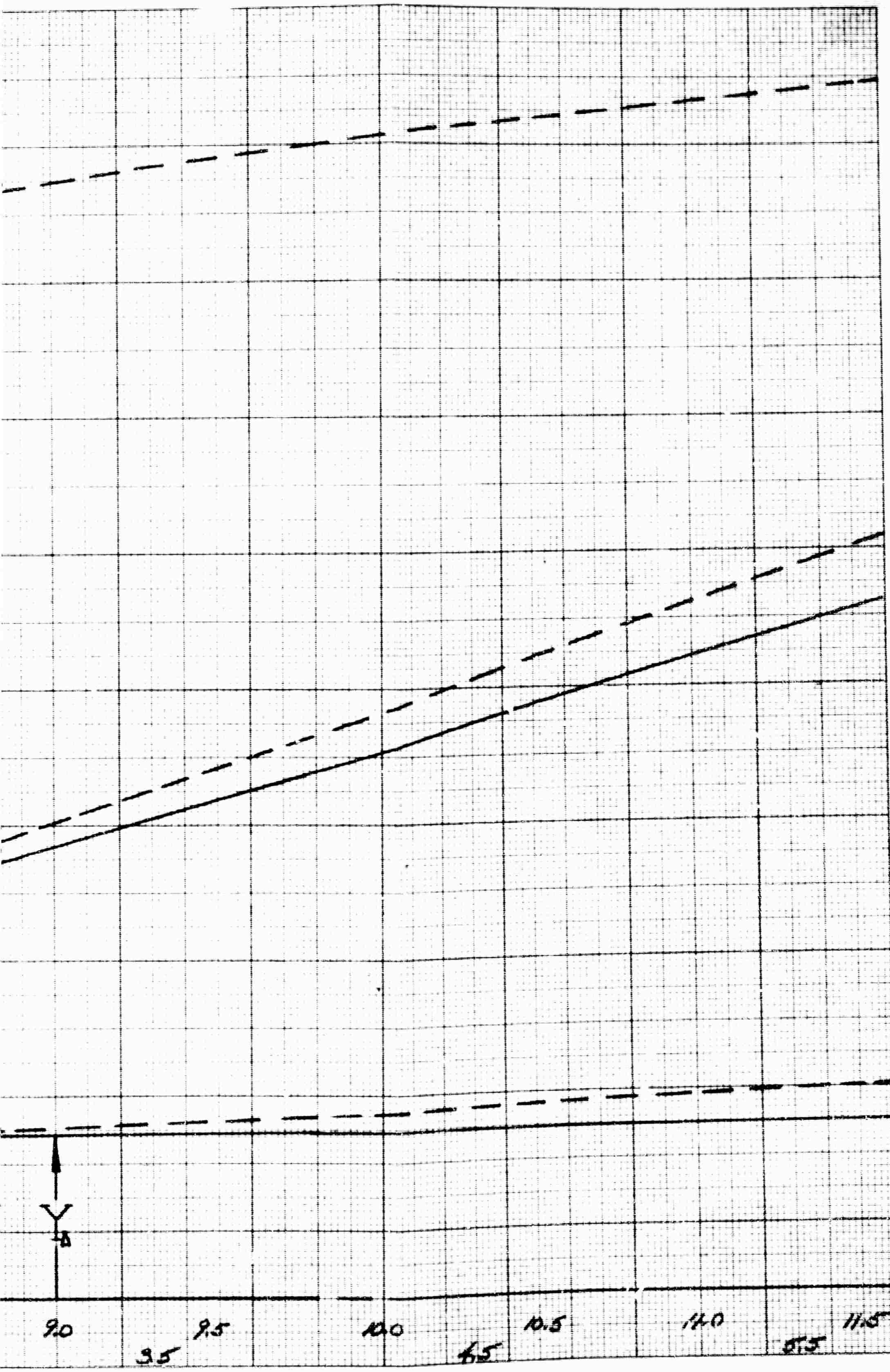


GASL
WESTBURY, N.Y.
SPHERICAL PELLET
DIA.= 3/16" VEL.=20KFPS
PRESSURE = 50 MMHG
—— ARGON T=300°K
- - - - AIR T=300°K
FIG. NO 1
BOW SI
BODY
Y/R_N
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
.5
1.0
1.5
2.0
2.5
A


SHOCK
INVISCID RE
DY STREAMLINE
S/R_N
3.0
3.5
4.0
4.5
5.0
5.5
X/R_N



TRAILING SHOCK
VISCOUS WAKE REGION
B
6.0
6.5
7.0
7.5
8.0
8.5
.5
1.5
2.5
X'/R


Y
9.0
9.5
10.0
10.5
11.0
11.5
3.5
4.5
5.5

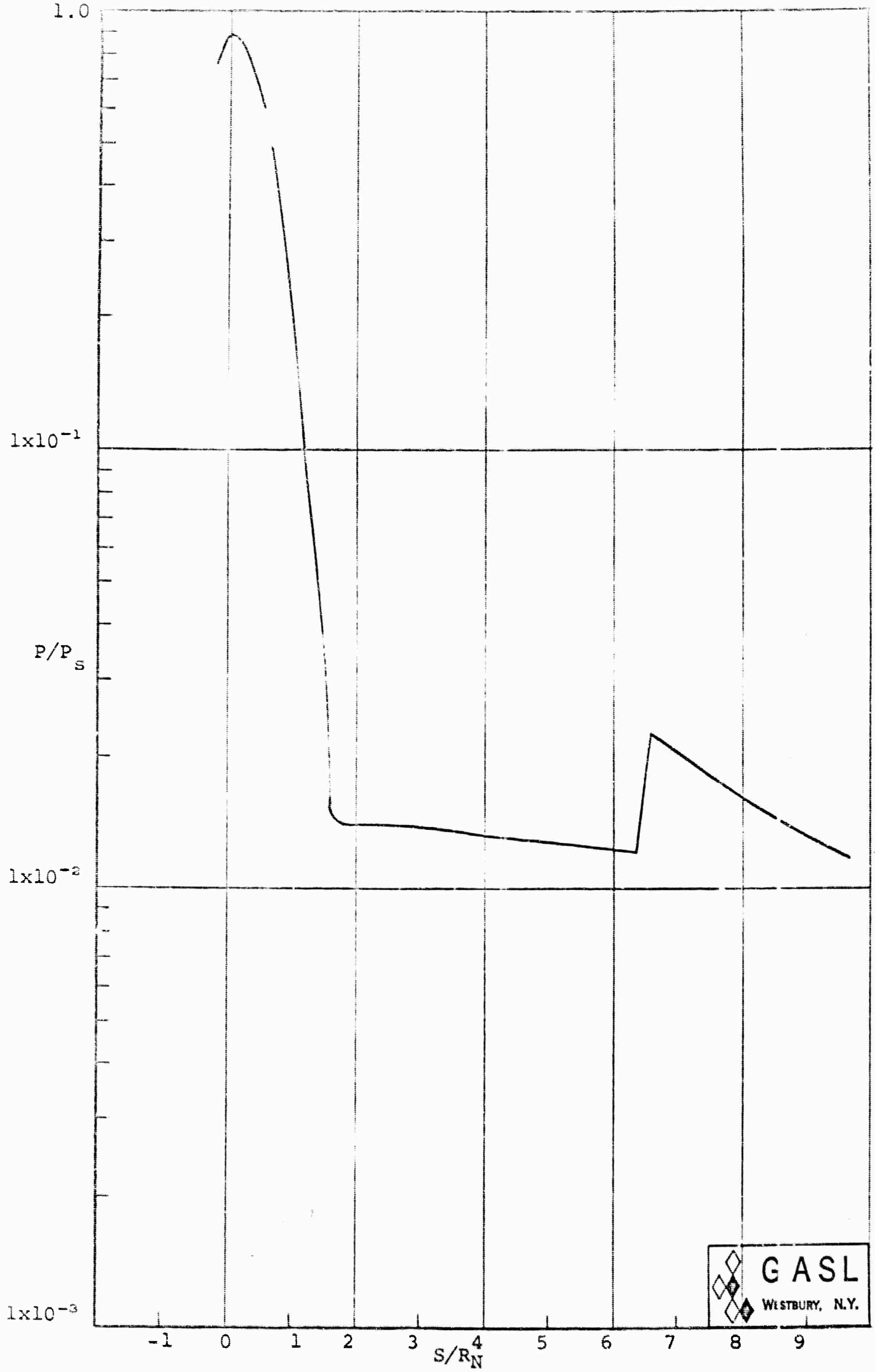


FIG. 2: BODY STREAMLINE PRESSURE DISTRIBUTION

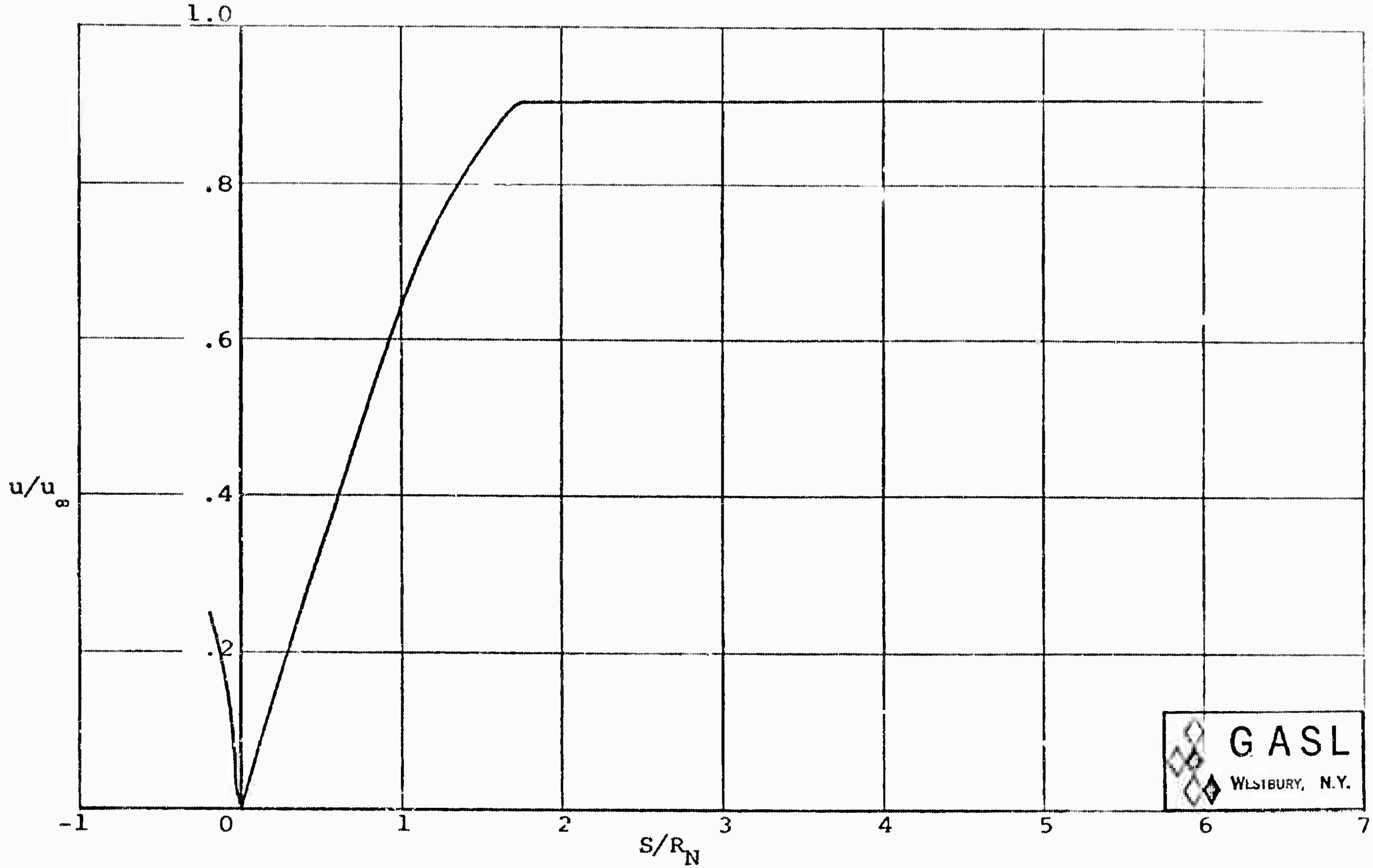


FIG. 3: VELOCITY ALONG BODY STREAMLINE

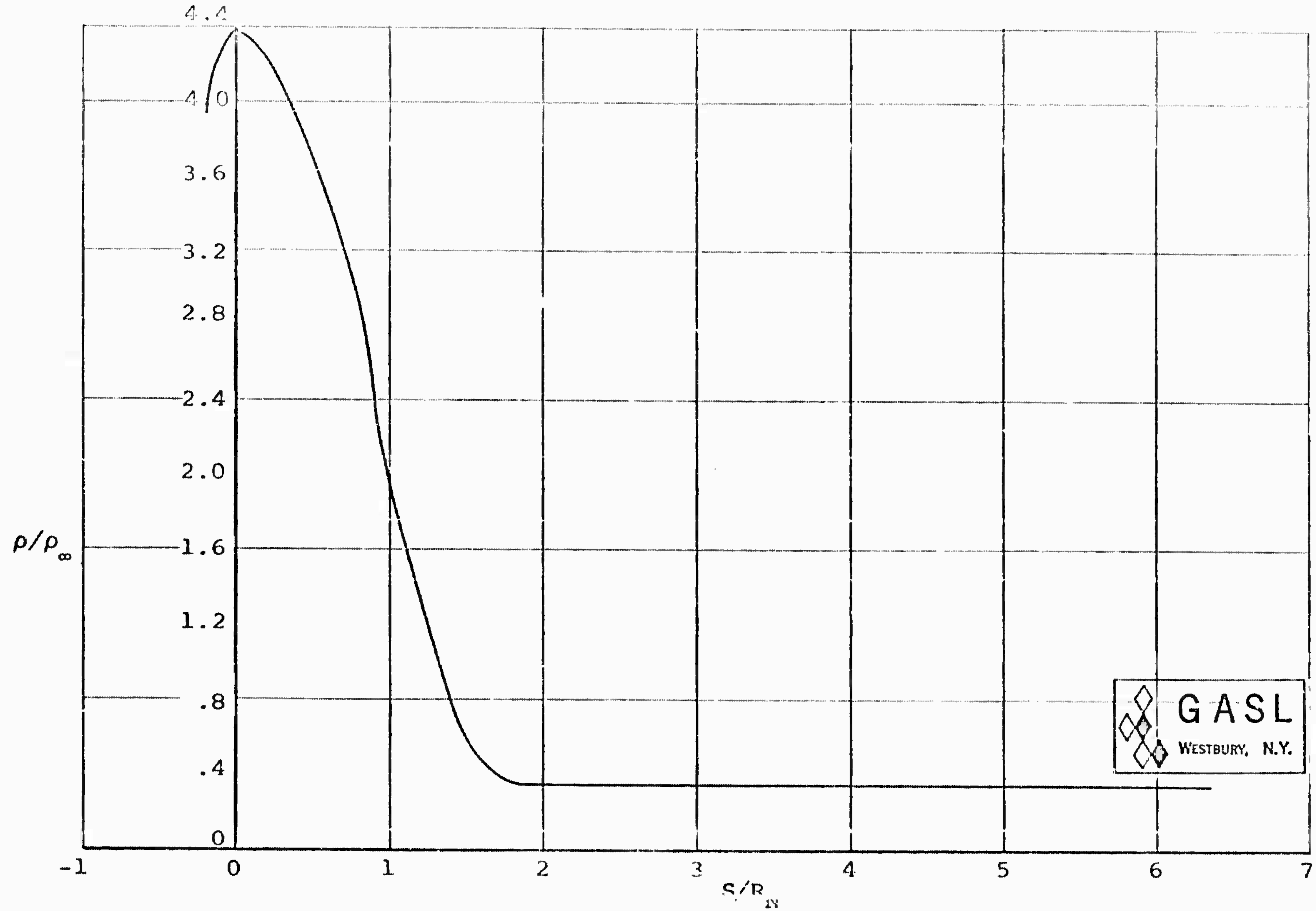


FIG. 5: DENSITY DISTRIBUTION ALONG BODY STREAMLINE

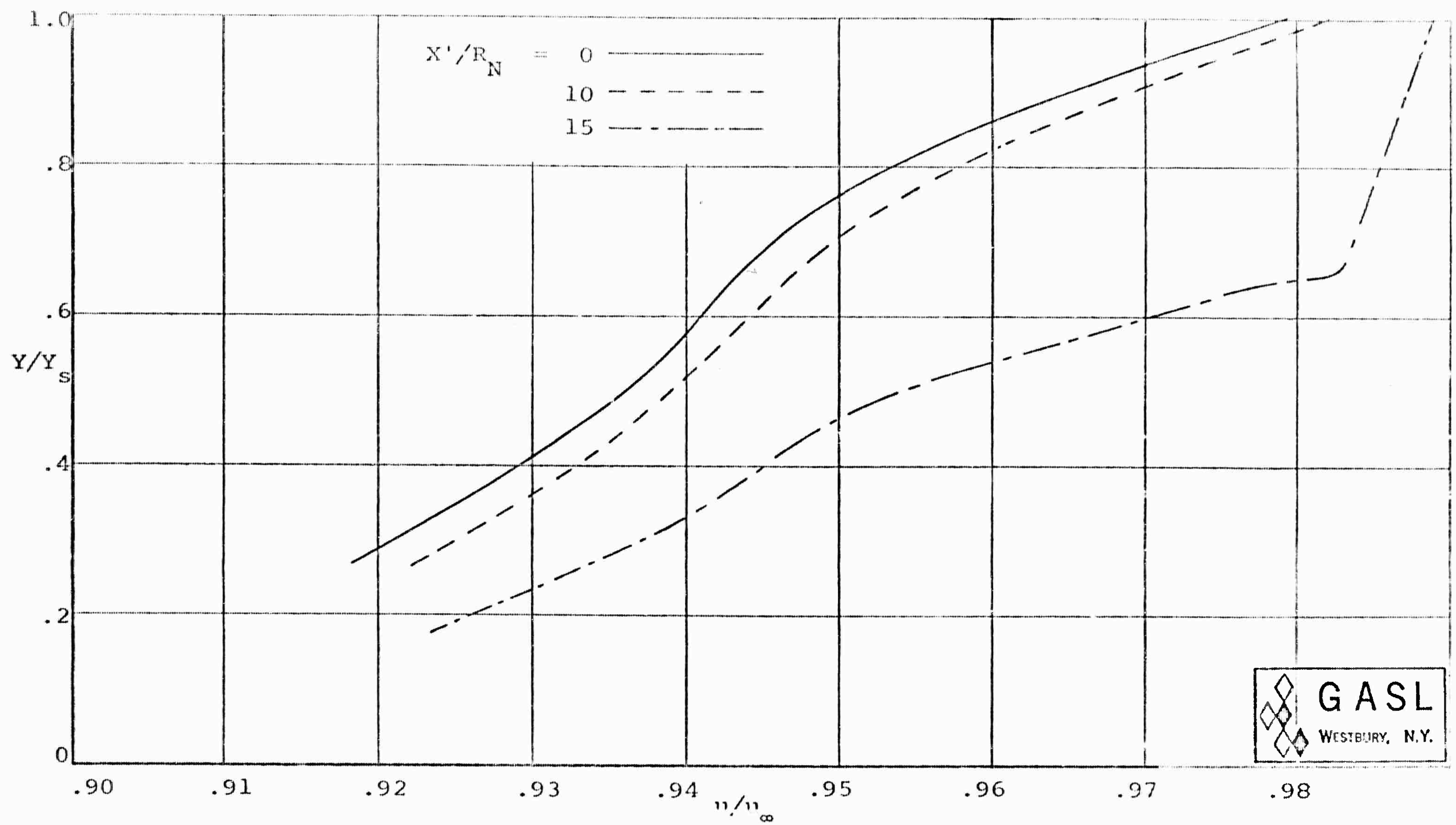


FIG. 7: VELOCITY PROFILES IN INVISCID REGION

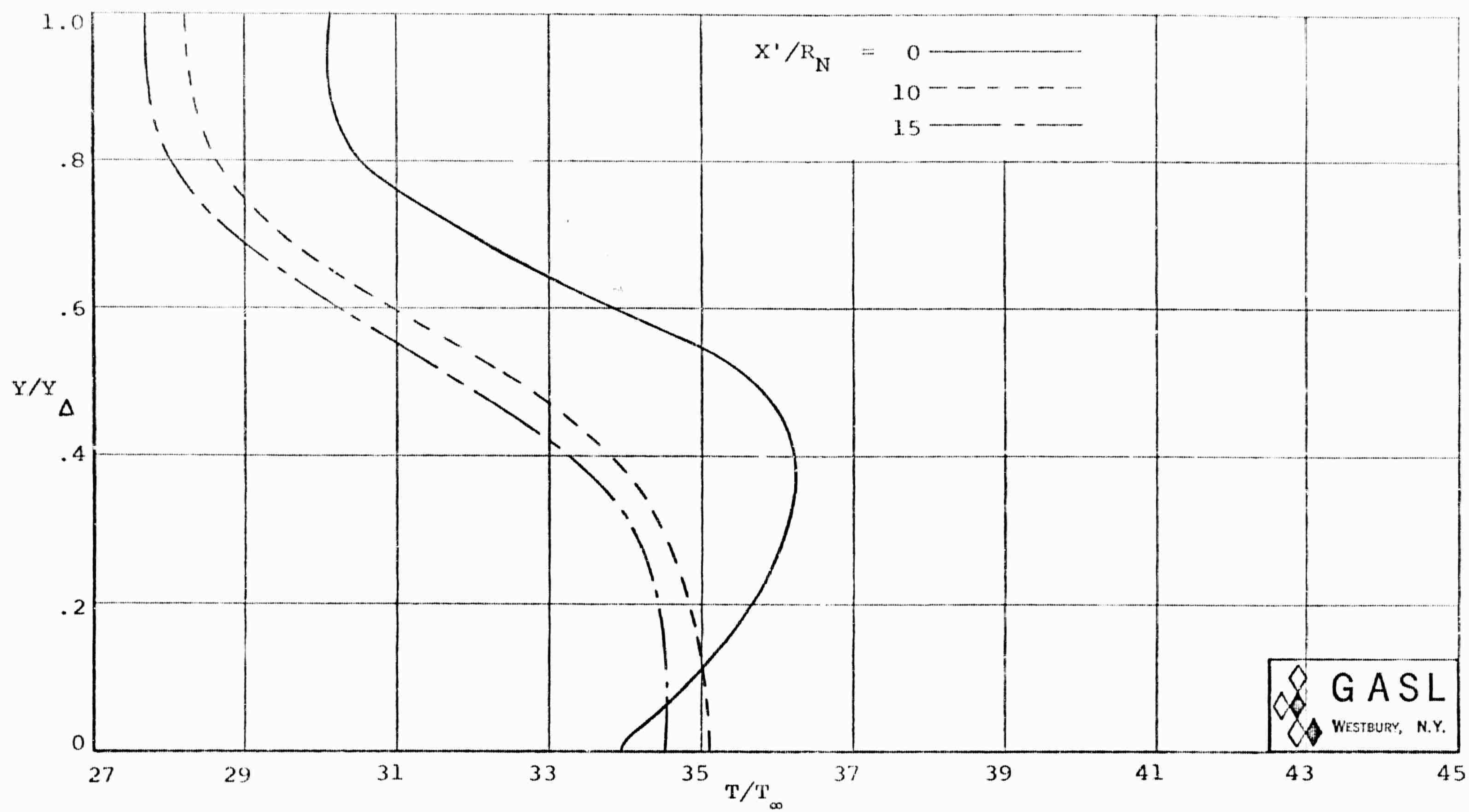


FIG. 8: TEMPERATURE PROFILES IN VISCOUS WAKE REGION

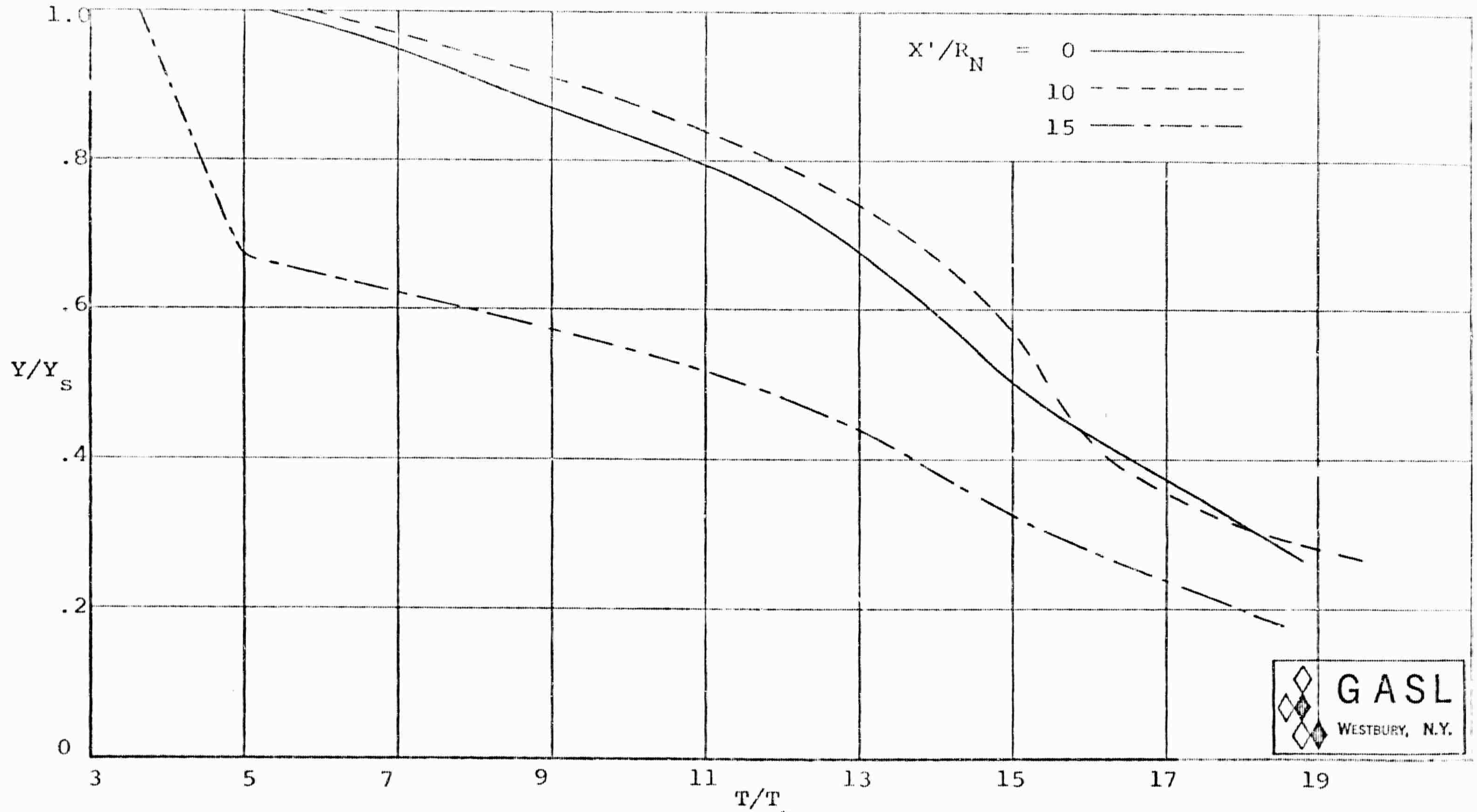


FIG. 9: TEMPERATURE PROFILES IN INVISCID REGION

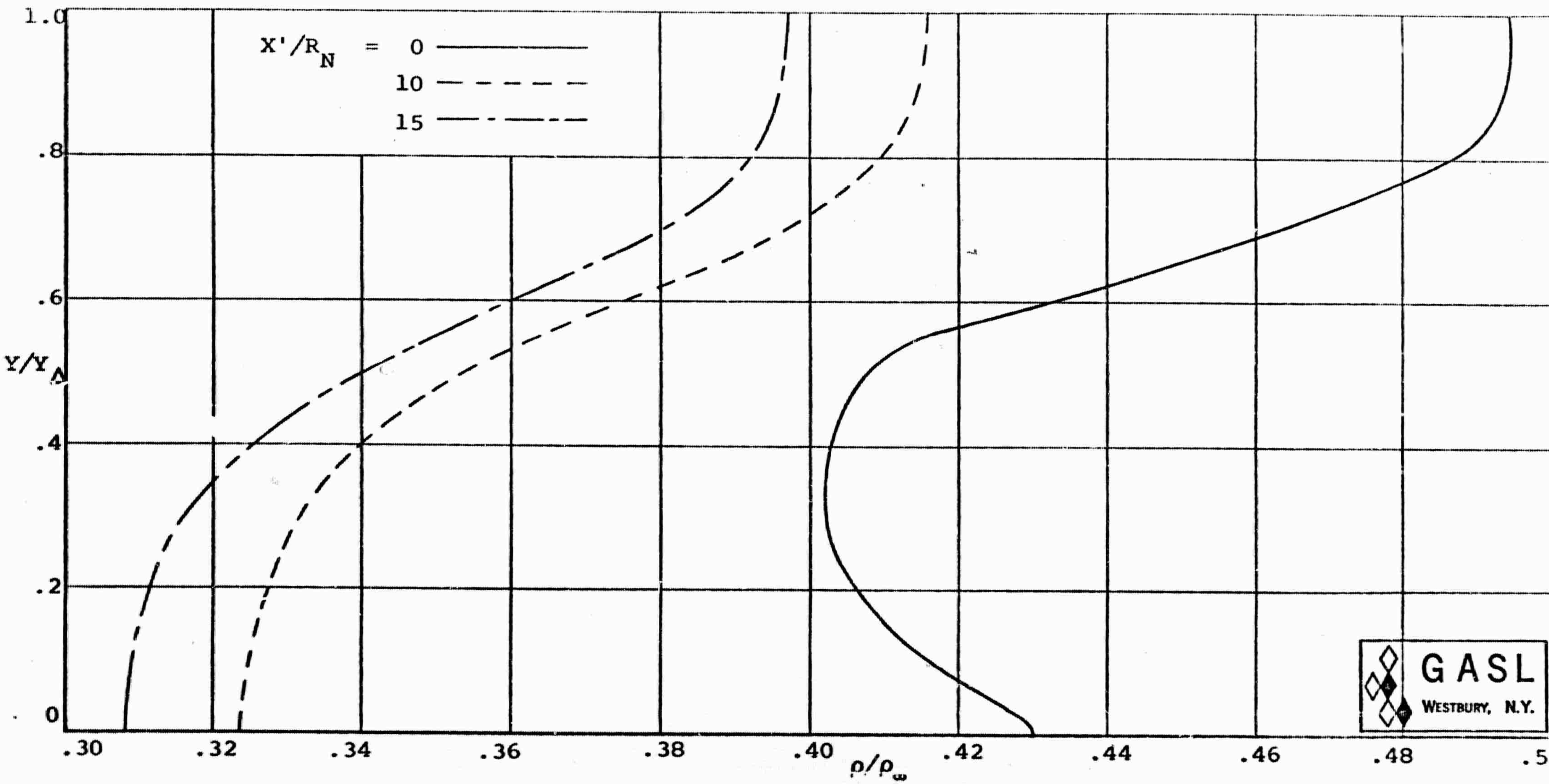


FIG. 10: DENSITY PROFILES IN VISCOUS WAKE REGION

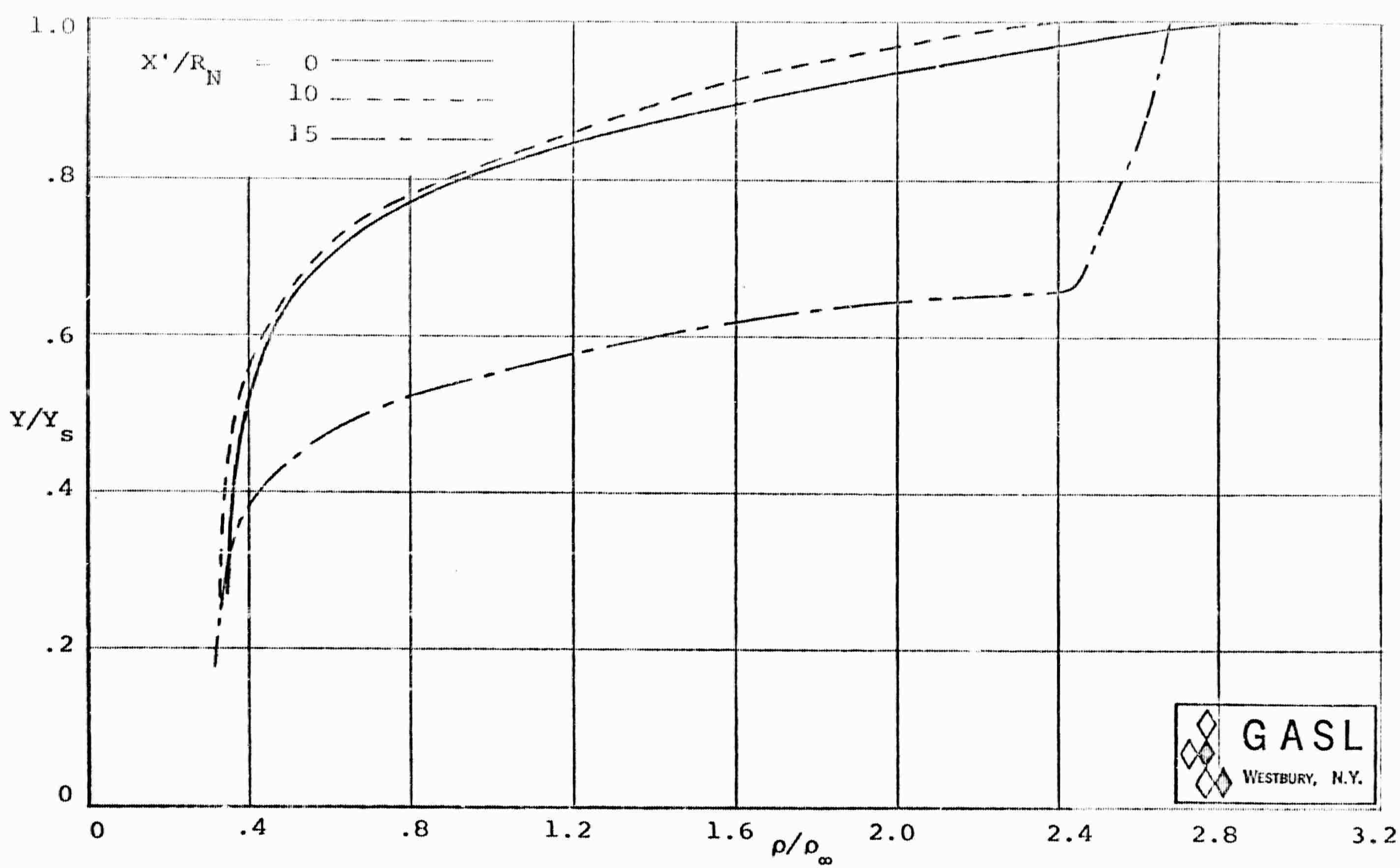


FIG. 11: DENSITY PROFILES IN INVISCID REGION

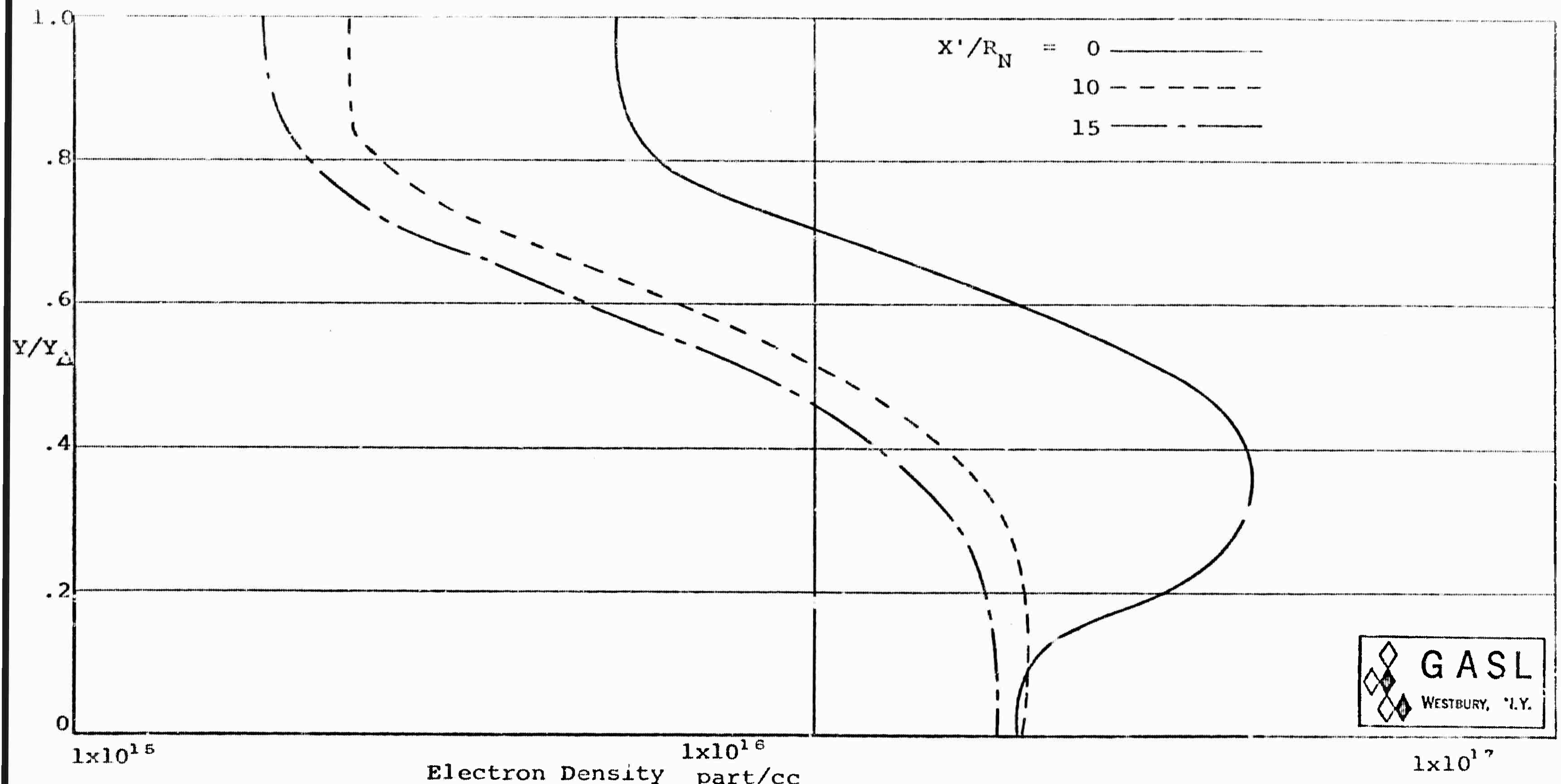


FIG. 12: ELECTRON DENSITY PROFILES IN VISCOUS WAKE REGION

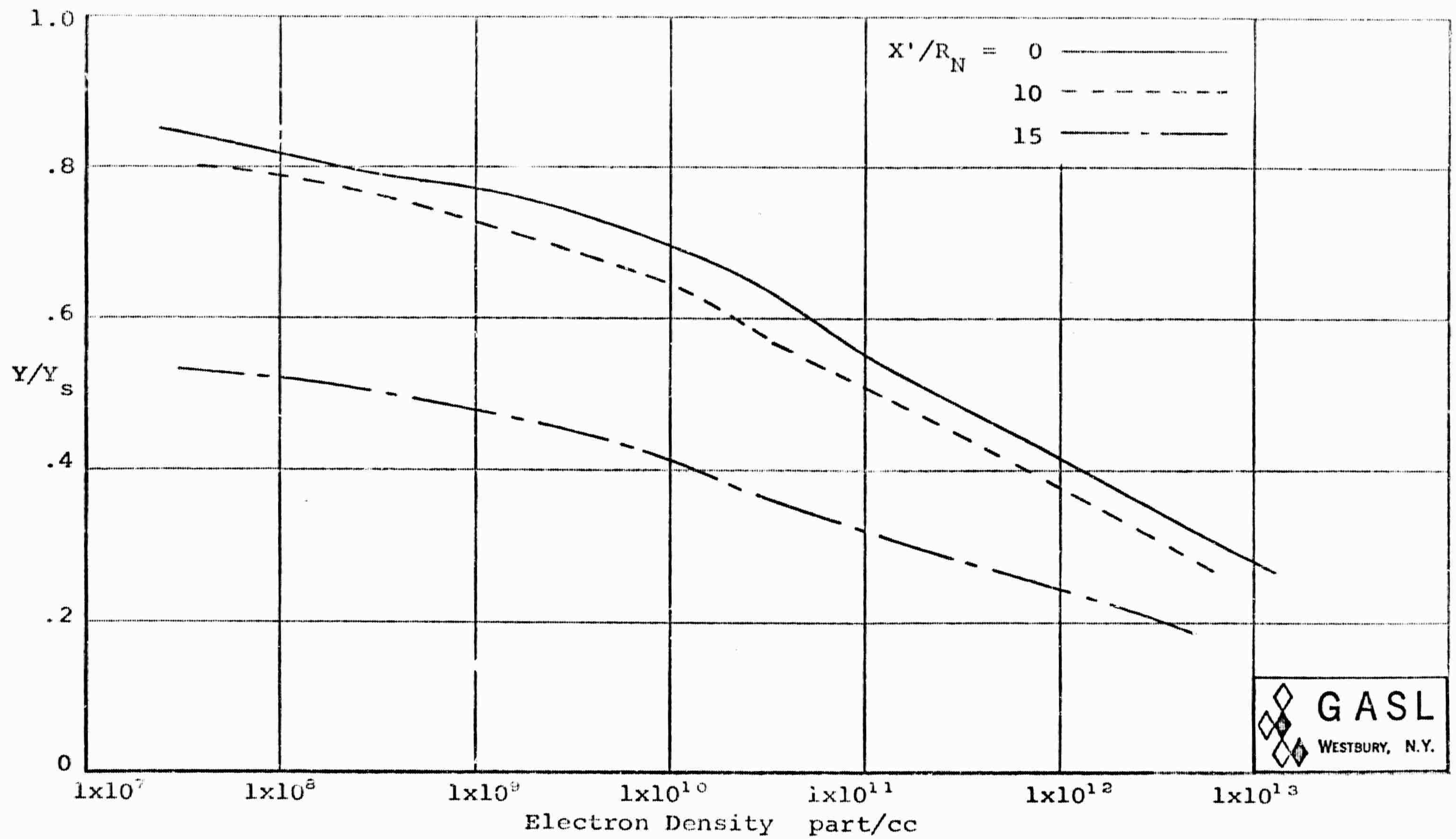


FIG. 13: ELECTRON DENSITY PROFILES IN INVISCID REJION

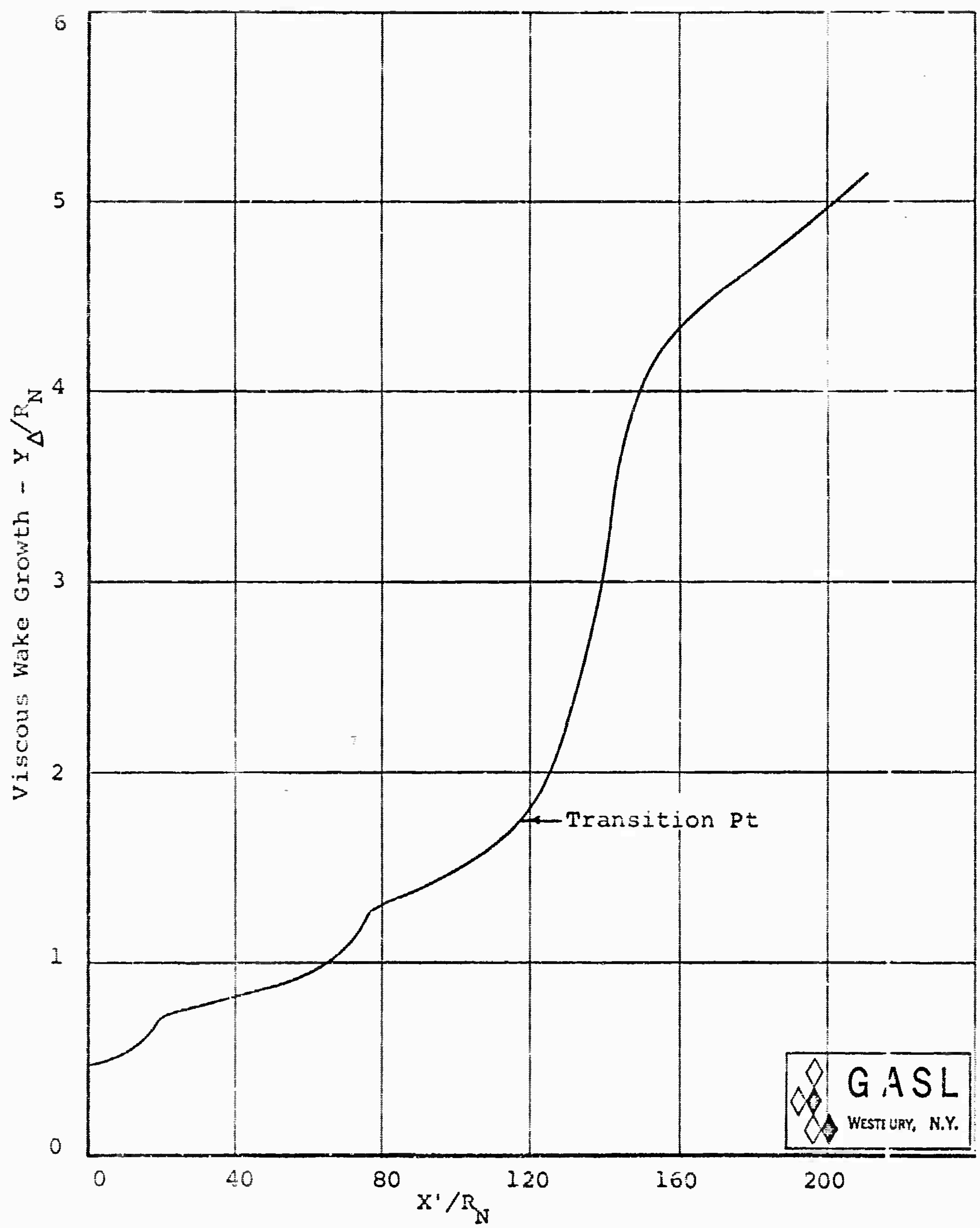


FIG. 14: GROWTH OF VISCOUS WAKE

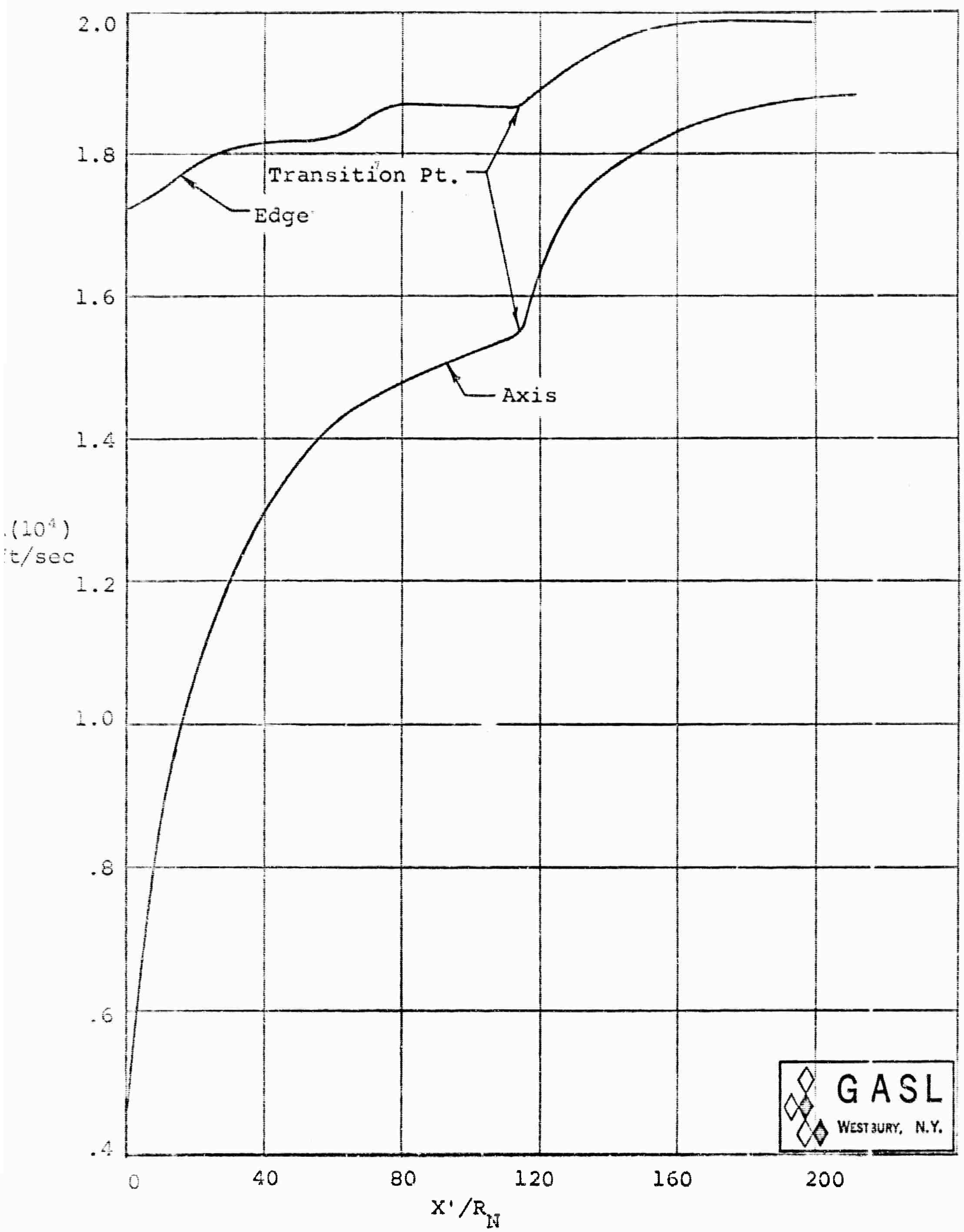


FIG. 15: VISCOUS WAKE AXIS AND EDGE VELOCITY

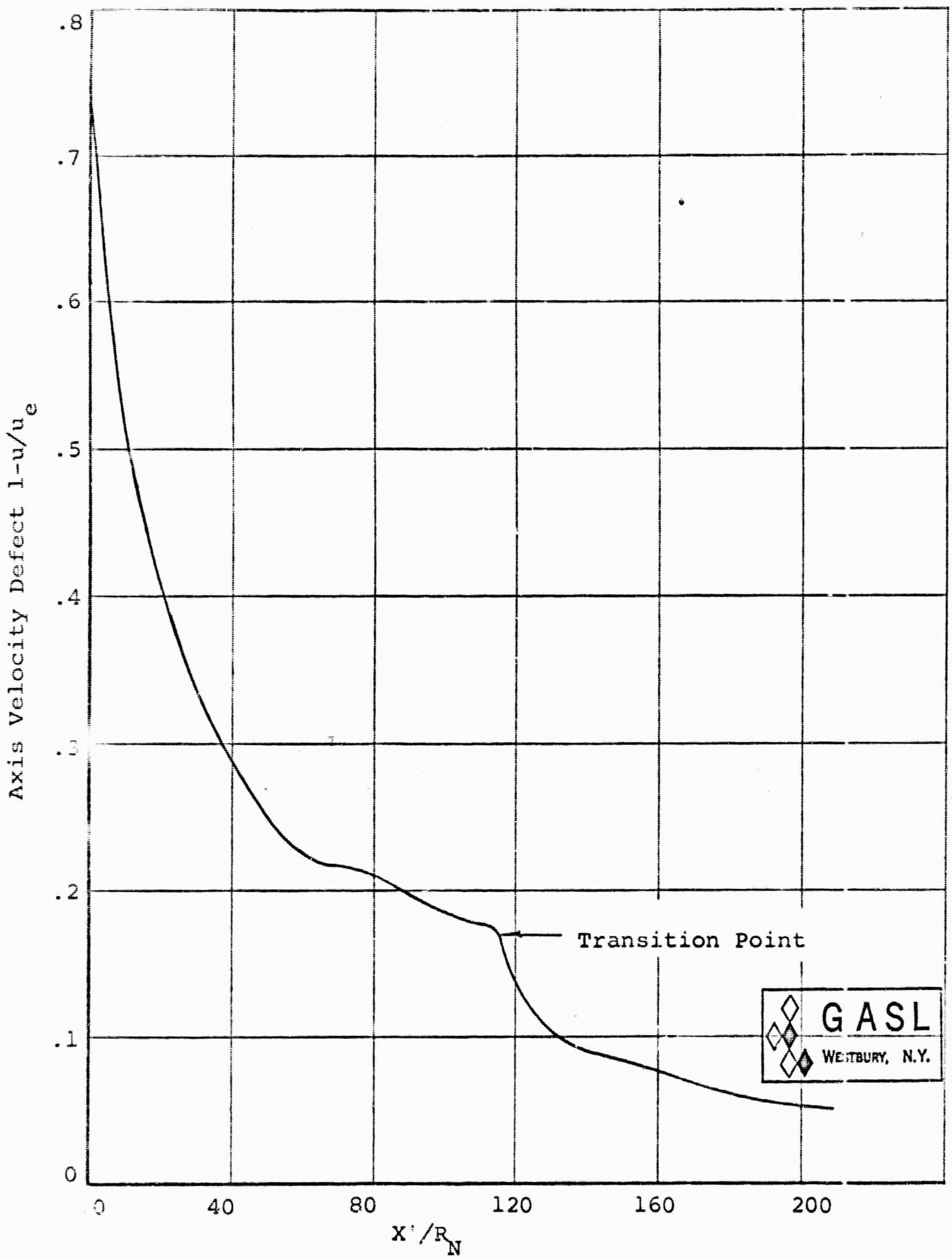

.8
.7
.6
.5
.4
.3
.2
.1
0
Axis Velocity Defect 1-u/u_e
Transition Point
GASL
WESTBURY, N.Y.
0
40
80
120
160
200
X'/R_N

FIG. 16

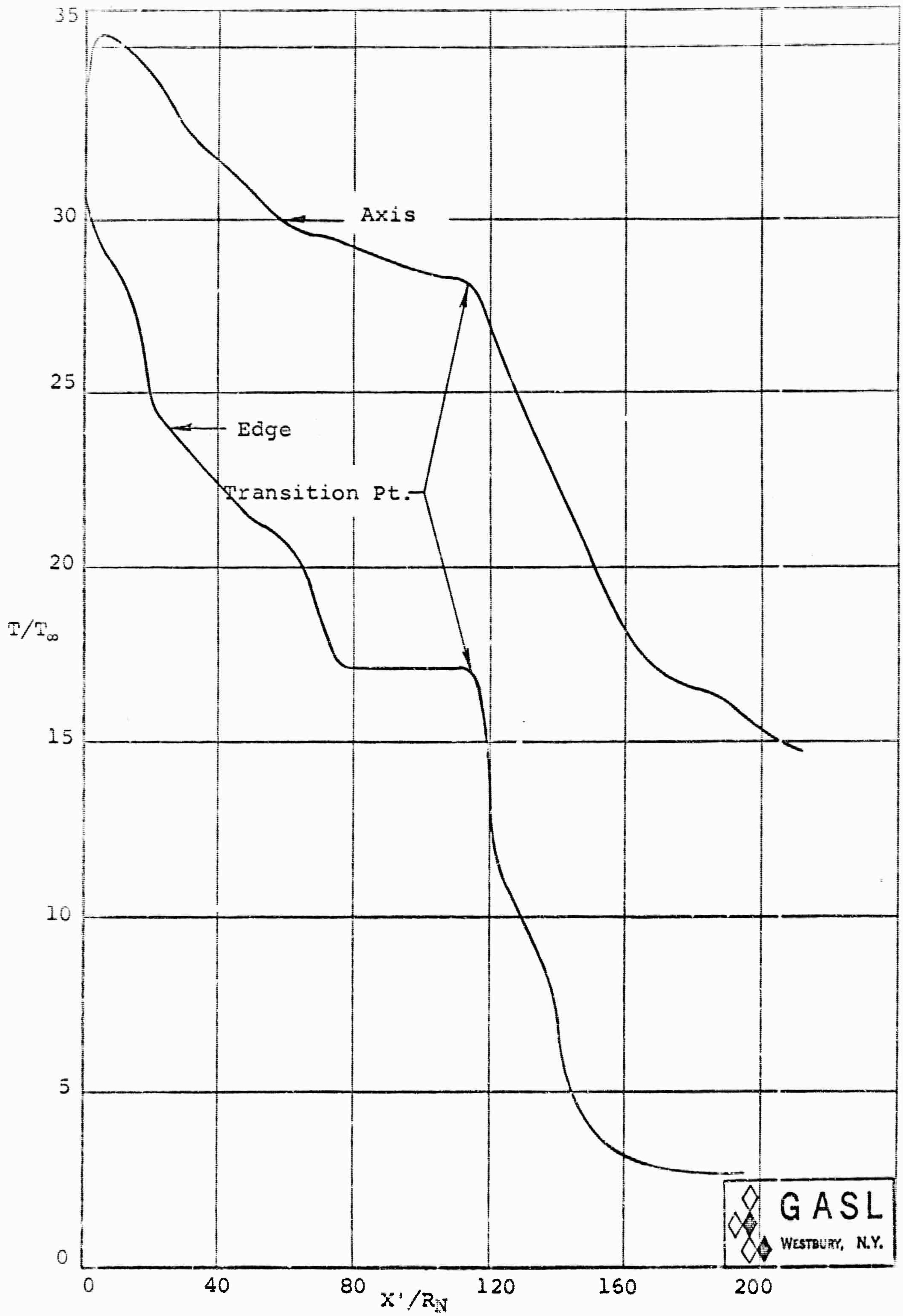


FIG. 17: AXIS AND EDGE TEMPERATURES IN VISCOUS WAKE REGION

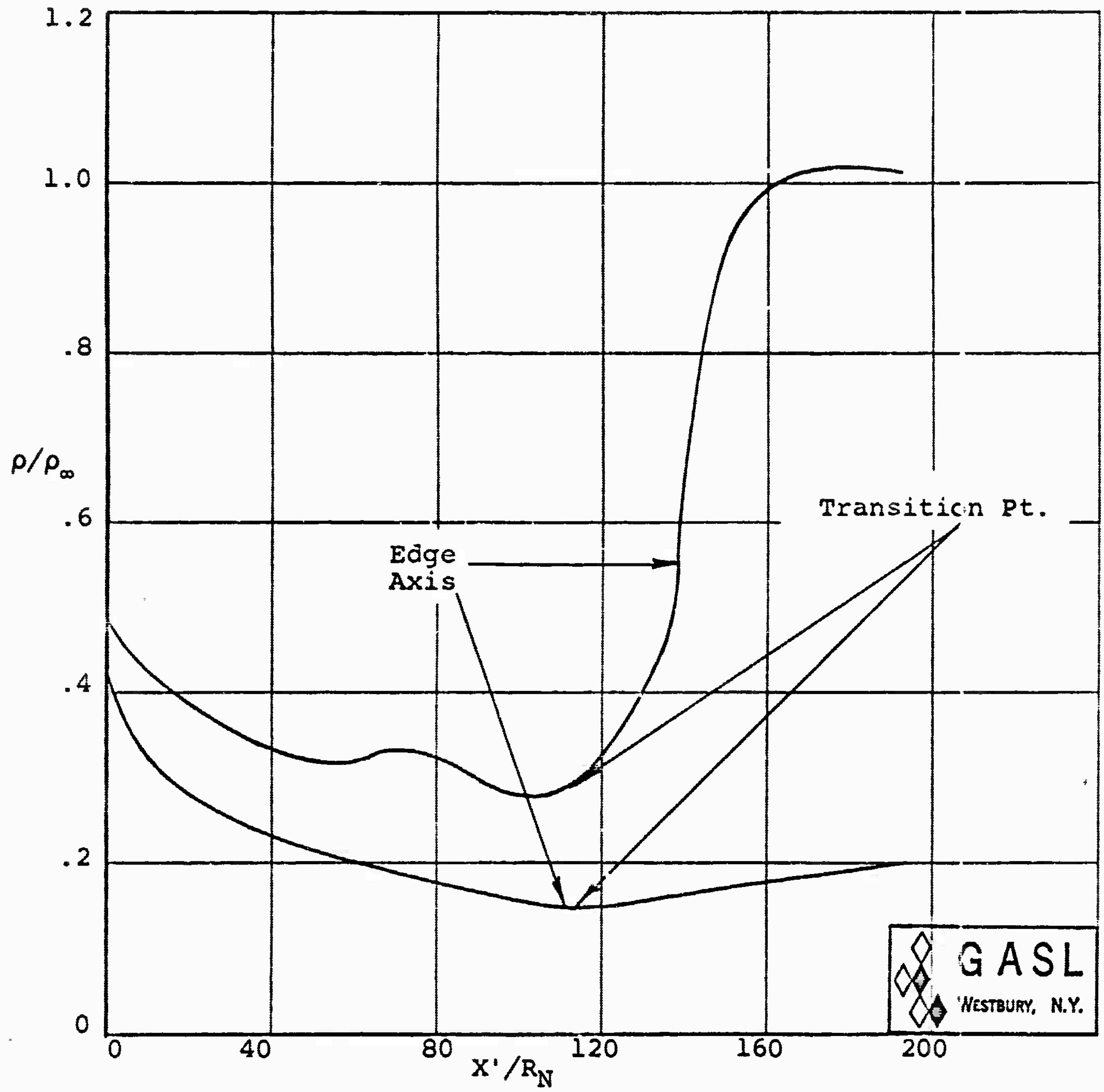


FIG. 18: AXIS AND EDGE DENSITIES IN VISCOUS WAKE REGION

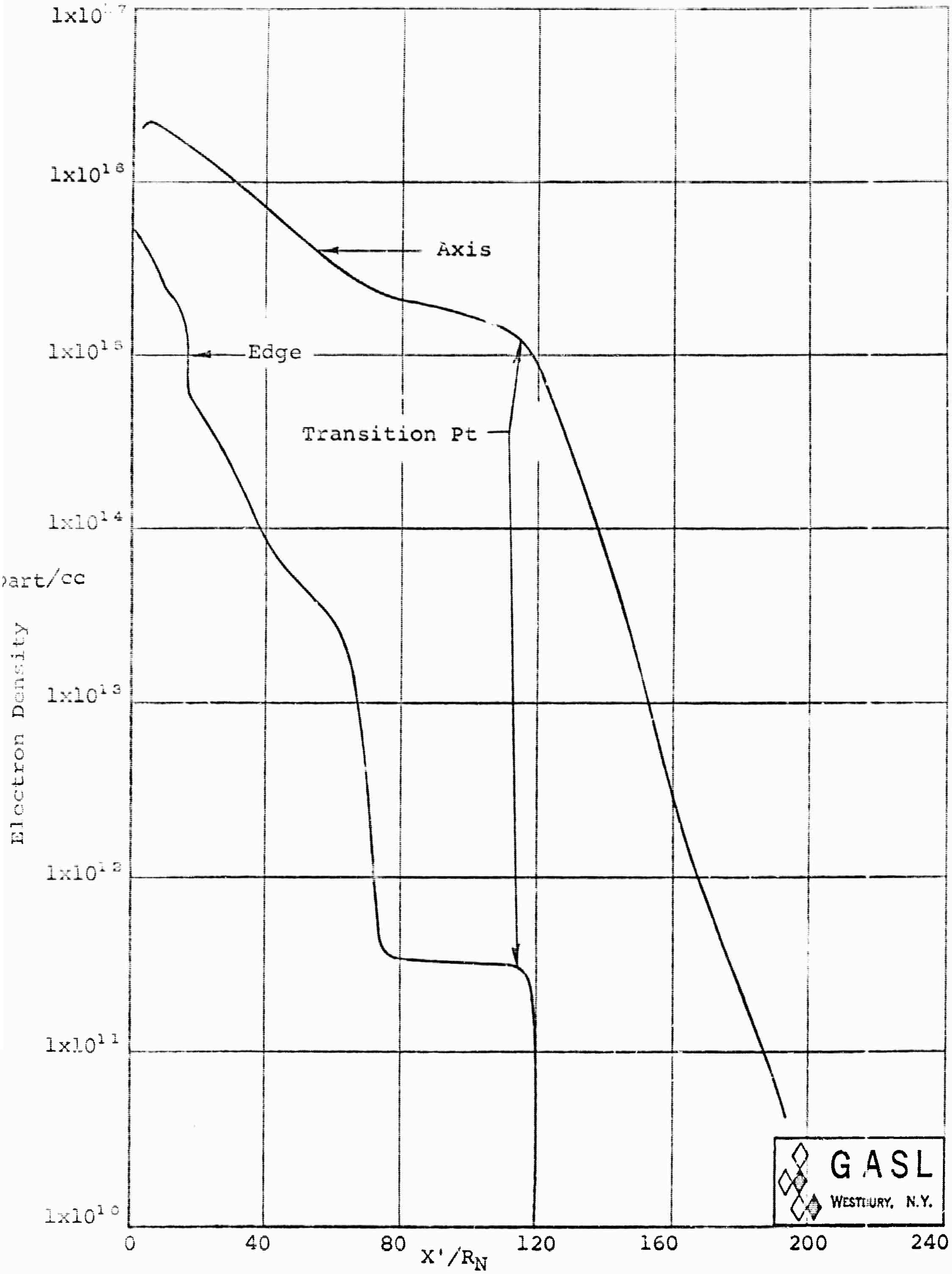


FIG. 19: AXIS AND EDGE ELECTRON DENSITIES IN VISCOUS WAKE

Project 8010
Rev. 10/31/64

DISTRIBUTION LIST

CONTRACT SD-149

Organization		No. of Cys.
Bell Telephone Laboratories Whippany, New Jersey Attn: Dr. C. W. Hoover	(84-8010-1)	1
Institute for Defense Analyses 400 Army-Navy Drive Arlington, Virginia 22202 Attn: Classified Library Dr. J. Menkes		 1 1
Weapons Systems Evaluation Group The Pentagon, Washington, D.C. 20301 Attn: Dr. John Daniel	(84-8010-3)	1
Director of Defense Research & Engr. (Strategic Weapons) The Pentagon, Washington, D.C. 20301 Attn: Cdr. R. H. Wertheim	(84-8010-4)	1
Stanford Research Institute Missile Defense Analysis Project 3322 South Memorial Parkway Suite 137 Huntsville, Alabama Attn: Dr. Irving Yabroff	(34-8010-5)	1
Aeronutronic Division Philco Corporation Newport Beach, California Attn: Mr. John Knudsen	(84-8010-6)	1
General Electric Company TEMPO Division 735 State Street Santa Barbara, California Attn: Mr. L. I. Kopeikin	(84-8010-7)	1
Ballistic Systems Division (BSRV) Norton Air Force Base San Bernardino, California Attn: Col. D. C. Middlekauff	(84-8010-8)	10

Organization		No. of Cys.
General Electric Company (MSD) Philadelphia, Pennsylvania Attn: Dr. Rowe Chapman	(84-8010-9)	1
Defense Documentation Center Cameron Station Alexandria, Virginia	(34-8010-10)	20
Headquarters Strategic Air Command (OA) Offutt AFB, Nebraska	(34-8010-11)	1
Commander U. S. Naval Ordnance Laboratory White Oak, Silver Spring, Md. Attn: Code BG (V. C. Dawson)	(34-8010-12)	1
Institute of Naval Studies 545 Technology Square Cambridge 39, Massachusetts Attn: George L. Street, Capt., USN	(34-8010-13)	1
Air Force Avionics Laboratory AVWW/ECM Technology Wright-Patterson AFB, Ohio 45433	(34-8010-14)	1
Stanford Research Institute Menlo Park, California Attn: Mr. Ralph Rapp	(34-8010-15)	1
Space Technology Laboratories, Inc. Florida Division P. O. Box 5277 Patrick AFB, Florida 32925 Attn: Technical Library	(84-8010-17)	1
AVCO Corp. Everett Research Laboratories Everett, Massachusetts Attn: Dr. R. Taylor	(34-8010-18)	1

Organization		No. of Cys.
Bureau of Weapons Dept. of the Navy Special Projects Office Washington, D.C. Attn: Cdr. A. Julian	(84-8010-19)	5
Kam..n Nuclear Garden of the Gods Road Colorado Springs, Colorado Attn: Dr. John Hoffman	(34-8010-21)	1
Battelle Memorial Institute 505 King Avenue Columbus, Ohio Attn: DEFENDER (Ed Ungar)	(34-8010-22)	1
Defense Research Corporation P.O. Box 3587 Santa Barbara, California 93105 Attn: Mr. Ben Alexander	(84-8010-23)	1
AVCO Corporation (RAD) 201 Lowell Street Wilmington, Massachusetts Attn: Mr. Dan Hritzay	(84-8010-24)	1
Sandia Corporation Albuquerque, New Mexico Attn: Mr. Charles Winter	(84-8010-25)	1
Commander U.S. Naval Weapons Laboratory Dahlgren, Virginia Attn: Code: KRT(MODE)	(34-8010-27)	1
Lincoln Laboratory Massachusetts Institute of Technology Lexington, Massachusetts		
Attn: Dr. C. R. Wieser	(34-8010-28)	1
Dr. A. Nedzel	(34-8010-29)	1
Library	(34-8010-30)	2
Dr. M. Herlin - Group 35	(34-8010-32)	1
Dr. S. Edelberg - Group 35	(34-8010-33)	1
Dr. S. Slattery - Group 35	(34-8010-34)	1
Dr. J. Hermann - Group 35	(34-8010-35)	1
Dr. W. Kornegay - Group 35	(34-8010-36)	1
Dr. B. Bryant - Group 35	(34-8010-37)	1
Dr. G. Pippert - Group 35	(84-8010-38)	1
Dr. M. Balser - Group 35		1

Organization		No. of Cys.
Lincoln Laboratory Massachusetts Institute of Technology PRESS Field Station APO 555, Box 58 San Francisco, California 96555		
Attn: Dr. M. Labitt	(104-8010-39)	1
Mr. K. Kressa	(104-8010-41)	1
Commanding General		
Attn: Mr. E.J. Little/AMSMI-RNR USAMICOM Redstone Arsenal Huntsville, Alabama	(34-8010-42)	1
Institute of Science & Technology The University of Michigan Box 618 Ann Arbor, Michigan Attn: BAMIRAC Library	(34-8010-44)	1
Raytheon Company Attn: Mr. A. Truszanowski Sudbury, Massachusetts	(104-8010-45)	1
R.C.A. Laboratories Moorestown, New Jersey Attn: Mr. Archie Gold	(34-8010-47)	1
Advanced Research Projects Agency Washington, D.C. 20301		
Attn: Dr. B. Fisher	(34-8010-48)	1
Dr. C.D. Fitz	(34-8010-49)	1
Mr. R. Zirkind	(34-8010-50)	1
Technical Information Office	(34-8010-51)	3
Mr. C. McLain, Rm. 2B-263	(34-8010-52)	1
Foreign Technology Division Wright-Patterson Air Force Base, Ohio Attn: TD-FCS (Schmidt)	(64-8010-54)	1
Conductron Corporation 393 S. Main Street Ann Arbor, Michigan Attn: Dr. K. Siegel	(64-8010-55)	1

Organization		No. of Cys.
Syracuse University Research Corp. Syracuse, New York Attn: Paul Howells	(64-8010-56)	1
Picatinny Arsenal U. S. Army Dover, New Jersey 07801 Attn: SMUPA-VL	(64-8010-57)	1
General Motors Defense Research Labs. Aerospace Operations Department Santa Barbara, California Attn: Dr. Colin Maiden	(64-8010-58)	1
Aeroelastic and Structures Laboratory Massachusetts Institute of Technology Cambridge, Massachusetts Attn: Dr. Emmitt A. Witmer	(64-8010-59)	1
National Engineering Science Company 711 South Fair Oaks Avenue Pasadena, California Attn: Dr. Richard Tracey	(64-8010-60)	1
Douglas Aircraft Company Missile and Space Systems Division Reentry Systems Advanced Programs Santa Monica, California Attn: V. E. Crosley	(84-8010-61)	1
TRW/Space Technology Laboratories One Space Park Redondo Beach, California Attn: Dr. William S. Carlson	(64-8010-62)	1
Sperry Gyroscope Co. Great Neck, New York Attn: Mr. K. B. Erkenbrack	(84-8010-63)	1

Project 8010

Organization		No. of Cys.
Flui Dyne Engineering Corp. 5900 Olson Memorial Highway Minneapolis, Minnesota 55422 Attn: Dr. James S. Holdhusen	(84-8010-64)	1
Aerospace Corporation P.O. Box 1308 San Bernardino, California Attn: Mr. K. Pierce	(84-8010-65)	2
Mr. G. Milburn	(84-8010-66)	2
Deputy for Studies and Analyses Research and Technology Division Attn: SESOM (Lt. Col. Greer) Wright-Patterson AFB, Ohio	(84-8010-67)	1